Exhibit C

Bluetooth®

Bluetooth 5

Go Faster. Go Further.

Bluetooth® 5 is a transformative update that significantly increases the range, speed, and broadcast messaging capacity of Bluetooth applications and makes use cases in smart home automation, enterprise, and industrial markets a reality.

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1.0 introduction

1.0 Introduction

According to a paper by Goldman Sachs, in the 1990s there were approximately 1 billion devices connected to the internet. In the 2000s, the *age of the smartphone*, this figure rose to 2 billion. ABI Research now forecasts that by 2021 there will be 48 billion devices connected to the internet, in what we're likely to term *the age of the IoT*. Of those 48 billion devices, 30% are forecasted to include Bluetooth technology.

This is no coincidence. Bluetooth Low Energy (LE) has been actively evolved to make it a key enabler of the Internet of Things (IoT), focusing on the edge tier of IoT systems. Bluetooth 5 brings some major advances to the technology and makes it ideal for an even broader range of IoT scenarios.

In this paper, we will present and explore the key advances in Bluetooth 5.

48 BILLION

devices will be connected to the internet by the year 2021 — of those, **30%** are forecasted to include Bluetooth technology.

2.0 a choice of three PHYs

2.0 A Choice of Three PHYs

The PHYsical Layer

Bluetooth is a full protocol stack. The bottom layer of the stack is called the Physical Layer and is normally referred to as *PHY*.

Bluetooth 5 adds two new PHY variants to the PHY specification used in Bluetooth 4. Each PHY variant has its own particular characteristics and was designed with specific aims in mind. The three PHYs have been named to allow them to be easily referenced in specifications. Their names are *LE 1M*, *LE 2M*, and *LE Coded*.

LE 1M

LE 1M is the PHY used in Bluetooth 4. It uses Gaussian Frequency Shift Keying and has a symbol rate of 1 mega symbol per second (Ms/s). It continues to be available for use in Bluetooth 5 and it's support is mandatory.

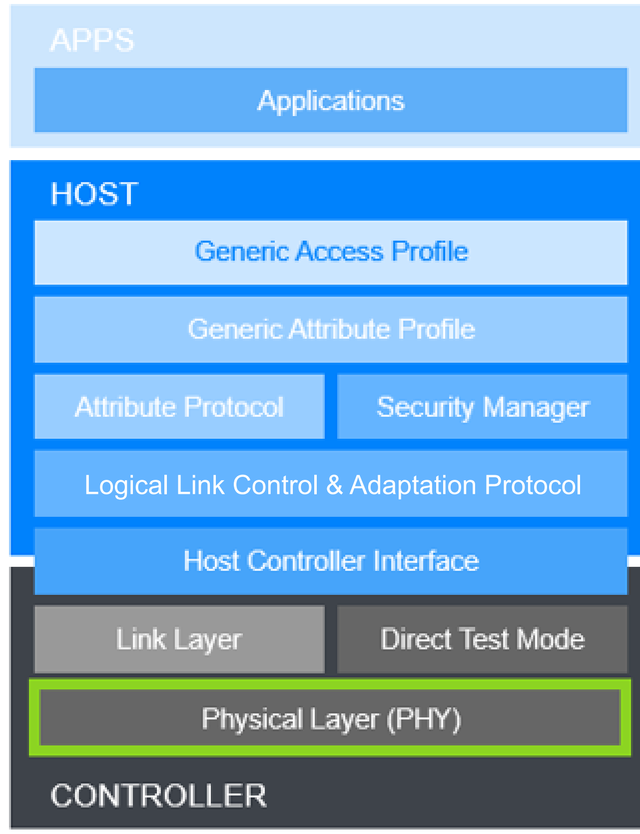


Figure 1 -The Bluetooth Low Energy protocol stack

3.0
LE 2M double the speed

3.0 A LE 2M Double the Speed

The new LE 2M PHY allows the physical layer to operate at 2 Ms/s and thus enables higher data rates than LE 1M and Bluetooth 4.

Factors Behind the Introduction of LE 2M

Many use cases involving Bluetooth LE tend to involve small amounts of data, perhaps transmitted only occasionally. But there are use cases gaining prominence which demand a low-power wireless communications technology which supports higher data rates.

Firmware upgrades are an important practice which, as well as delivering new functionality, will often deliver bug fixes and security improvements which help keep users, businesses, and industrial systems safe and secure. Being able to initiate and complete a firmware upgrade over the air quickly helps with the task of keeping device firmware up to date. Consumers, in particular, are likely to be reluctant to apply firmware updates if their experience is that they take an excessive amount of time to complete.
User experience and human behaviour are as much a consideration in security as are the technical aspects.

Sports and fitness devices are getting increasingly sophisticated and now often measure multiple dimensions of the human body more frequently and with greater accuracy. A similar trend is taking place with some medical devices. The ECG has evolved from a device which had one lead to the 12 lead ECG of today.

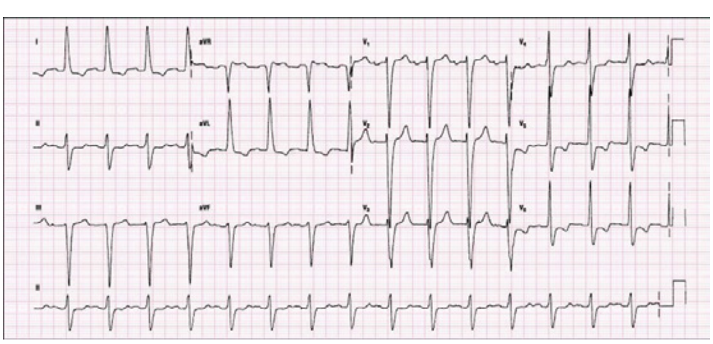


Figure 2 - We're collecting more data from sensors

Such changes bring with them a substantial increase in the amount of data being collected.

There's also been a rise in devices that act as buffered sensors, especially in fields like Lifestyle Analysis. Here, the user will wear a sensor, often for several days, before transferring all the accrued data to another device, such as a smartphone or computer.

Quantity of data is not the only driver behind the introduction of LE 2M. Transmitting a given amount of data using a reduced amount of air time also provides greater spectral efficiency.

Technical Aspects of LE 2M

The LE 2M PHY is characterized by using double the symbol rate that the LE 1M PHY uses and therefore double that of the Bluetooth 4 PHY. 2-level Gaussian Frequency Shift Keying (GFSK) continues to be used with binary zero represented by decreasing the carrier frequency by a given frequency deviation and a binary one represented by increasing the carrier frequency by the same deviation.

LE 1M uses a frequency deviation of at least 185 kHz. Higher symbol rates can produce greater amounts of inter-symbol interference however. To mitigate this, the LE 2M PHY uses a frequency deviation of at least 370 kHz.

4.0
4x range

4.0 4x Range

Range and Bluetooth 4

Bluetooth LE has a much longer range than is popularly believed to be the case, even at version 4. Informal testing by the author, using a standard smartphone and a Bluetooth LE MCU, demonstrated the successful receipt of Bluetooth notifications by the smartphone at a distance of over 350 meters from the MCU in an environment which was sub-optimal with respect to radio communication, containing numerous people and trees. And there are commercial Bluetooth modules on the market whose data sheets state that a range of 500 meters is possible.

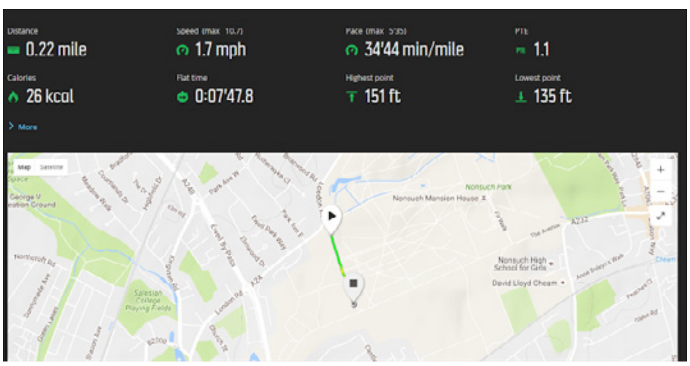


Figure 3 - Informal testing of Bluetooth 4 and range: 0.22 miles = 354 meters

Why Increase the Range of Bluetooth?

Given the fact that Bluetooth 4 has a remarkably healthy range for a low-power wireless communications technology, why increase it still further?

There are many use cases where greater range is advantageous. The smart home sector is one example and it has, to a degree, informed some of the goals behind Bluetooth 5 and its increased range.

The LE Coded PHY

The LE Coded PHY allows range to be quadrupled (approximately) compared to Bluetooth 4, and this has been accomplished without increasing the transmission power required.

To understand how this has been accomplished requires the question of what we mean by *range* in wireless communications systems to be answered.

Bluetooth is a radio technology and radio is a form of electromagnetic radiation. In the context of telecommunications, the question of maximum range is better expressed as *what is the maximum range at which data can be correctly extracted from the received signal*, rather than *how for can this electromagnetic energy travel and still be detected*.

The distinction relates to how we use radio to encode and transmit data and how background noise can impact the decoding of that data by a radio receiver. Symbols created by modulating a carrier signal to represent binary zeroes or ones get transmitted. The receiver must receive the signal, turn it back into the same symbols and, by extension, the same binary values higher up the stack. A transmitted zero, decoded by the receiver as a one or vice versa, represents an error.

The receiver has its work complicated by the fact that there is background radiation, or noise in the

4.0 4x Range

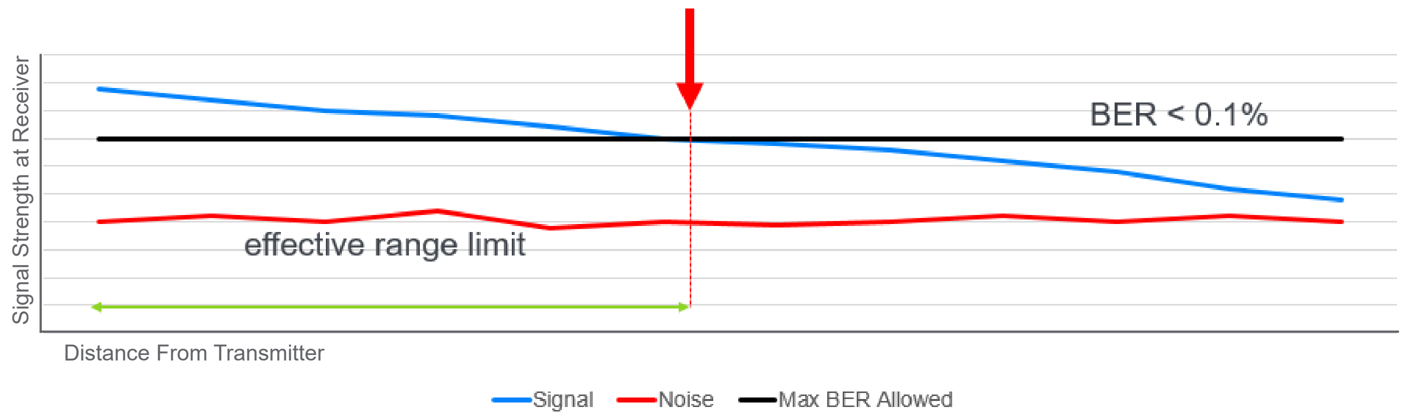


Figure 4 - Relationship between SNR and BER (not to scale)

environment. The closer the level of the background noise to that of the received signal, the harder it becomes to decode the received signal and, at some point, errors in the decoding process start to occur. Formally, we term the ratio of our transmitted signal power to that of the background noise the Signal-to-Noise Ratio (SNR). The strength of the received signal diminishes as the receiver moves further away from the transmitter and consequently, with a more or less constant background noise level, the SNR reduces. As such, the probability of decoding errors occurring increases.

We can quantify the level of errors experienced and we call this the Bit Error Rate (BER). BER is essentially the probability that a transmitted bit will be incorrectly decoded by the receiver. We can then state the limit to the BER, which we will tolerate at a given receiver input level. Bluetooth defines a BER of 0.1% as the limit which a receiver must achieve.

So, increasing the range of Bluetooth without increasing the transmitter power was really a problem concerned with achieving the same maximum permitted BER at a greater distance from the transmitter and, hence, at a lower SNR.

Dealing with Errors

In communications systems, errors are dealt with via two broad strategies. The first is Error Detection and the second is Error Correction.

Error Detection

There are various schemes which allow a receiver to detect errors. Parity bits were first used many decades ago in both paper and magnetic tape systems. Wired, serial communications systems still rely on parity bits to allow the receiver to detect that one or more bits has been incorrectly decoded.

There are also several types of checksum which can be used. Bluetooth uses a type of checksum known as a Cyclic Redundancy Check (CRC). All packets have a 24-bit CRC value calculated for them by the transmitter and appended to the packet. The receiver recalculates the CRC and compares the calculated value with the value appended to the packet. If they are not the same, an error has occurred.

In the event that errors are detected, systems may respond in one or two ways. They could regard the error as fatal and abandon the communication, or they could request or hint that the transmitter should send the data again in the hope that a subsequent attempt

4.0 4x Range

will be successful. Bluetooth causes the transmitter to retransmit data when a CRC check has failed, simply by not acknowledging the packet at the link layer. Failure to receive an acknowledgement causes the transmitter to send the data again.

Error Correction

It is possible to not only detect errors at the receiver, but also up to certain limits to correct them so that the receiver does not need to have the data retransmitted. Bluetooth LE at version 4 does not perform error correction, only error detection.

Correcting errors using advanced error-correction techniques has the major advantage that data can be correctly decoded at a lower SNR and, hence, at a greater distance from the transmitter. This is the basis upon which Bluetooth 5's increased range has been built. The LE Coded PHY uses Forward Error Correction (FEC) to correct errors. It works by adding additional redundant bits to the transmitted packets, whose sole purpose is to support the application of the FEC algorithm and to determine the correct value that erroneous bits should have.

In fact, the process adds two stages to the bit stream process in Bluetooth LE. This is depicted below:

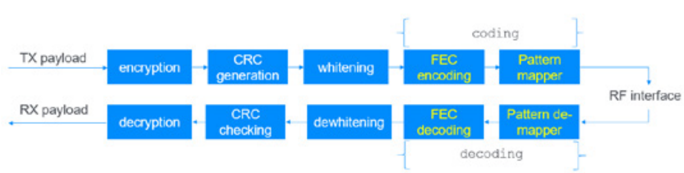


Figure 5 - FEC in Bluetooth 5 bit stream processing

FEC Encoding uses a convolutional encoder, which generates 2 bits for every input bit using the following generator polynomials:

$$G_0(x) = 1 + x + x^2 + x^3$$

$$G_1(x) = 1 + x^2 + x^3$$

Figure 6 - FEC in Bluetooth 5 bit stream processing

LE Coded may be used with a choice of 2 different coding schemes, termed S=2 and S=8. The Pattern Mapper converts each bit from the convolutional FEC encoder into P symbols, where the value of P depends on the coding scheme in use. If S=2 then, in fact, there is no change (i.e. P=1), but if S=8 then each bit from the FEC encoder produces 4 output bits (i.e. P=4) from the Pattern Mapper. Specifics are as shown below:

Input (from FEC Encoder)	Output with S=2	Output with S=8
0	0	0011
1	1	1100

Figure 7 - Pattern Mapper

The choice of coding scheme, S=2 or S=8, with the LE Coded PHY has two consequences. With S=2, range will be approximately doubled, whilst with S=8 it will be approximately quadrupled. But as can be seen, due to the requirement for redundant data to support the FEC algorithm at the receiver, it also impacts the number of symbols which must be transmitted. This reduces the overall data rate.

5.0 PHY selection

5.0 PHY Selection

Changing the Current PHY

The Host Controller Interface (HCI) supports a new command with which the *Change PHY Procedure* may be invoked by the host. This allows the host to select the PHY it wishes to use at any given time. It is envisaged that applications, for example, may wish to switch into 2Ms/s mode for those use cases where the highest data rates are required or switch to long-range mode when required.

Comparing the Three PHYs

The following table presents key metrics relating to the three PHYs in Bluetooth 5.

	LE 1M	LE Coded S=2	LE Coded S=8	LE 2M
Symbol Rate	1 Ms/s	1 Ms/s	1 Ms/s	2 Ms/s
Data Rate	1 Mbit/s	500 Kbit/s	125 Kbit/s	2 Mbit/s
Error Detection	CRC	CRC	CRC	CRC
Error Correction	NONE	FEC	FEC	NONE
Range Multiplier (approx.)	1	2	4	0.8
Bluetooth 5 Requirement	Mandatory	Optional	Optional	Optional

6.0 advertising extensions

6.0 Advertising Extensions

Advertising in Bluetooth 4

Advertising packets in Bluetooth 4 are 37 octets long with a 6 octet header and a payload of, at most, 31 octets. Advertising packets are transmitted on up to three dedicated channels numbered 37, 38, and 39 out of a total of 40 radio channels, each of which are 2MHz wide. The full set of channels are numbered from 0 to 39.

The same payload is typically transmitted on all three channels, one packet at a time.

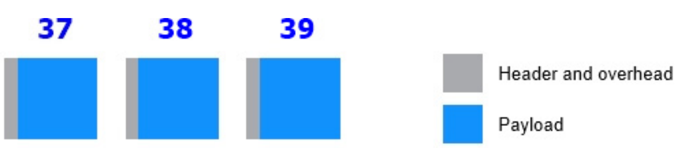


Figure 8 - Advertising and channel use in Bluetooth 4

Bluetooth 5 Advertising Extensions in Summary

There have been some major changes in how advertising may be performed in Bluetooth 5, compared with Bluetooth 4. Eight new PDUs relating to advertising, scanning, and connecting have been added to the Generic Access Profile. These changes allow much larger amounts of data to be broadcast in connectionless scenarios, advertising to be performed in a deterministic fashion, and multiple distinct sets of advertising data to be broadcast. There are significant improvements regarding contention and duty cycle too.

Bluetooth beacons are a major use case for Bluetooth advertising. It's forecasted that by 2021 over 565 million beacon products will be shipping per year. Bluetooth 5 provides the basis for creating next-generation beacons, which will allow much richer, multi-faceted sets of contextual data to be broadcast by beacons, rather than just an ID or URL. It's easy to envisage a vending machine or refrigerator broadcasting its location ID, temperature, stock level, battery level, number of times the door has been opened, and other maintenance indicators all at once, for example.

The next sections explore each aspect in the Bluetooth 5 advertising extensions feature in turn.

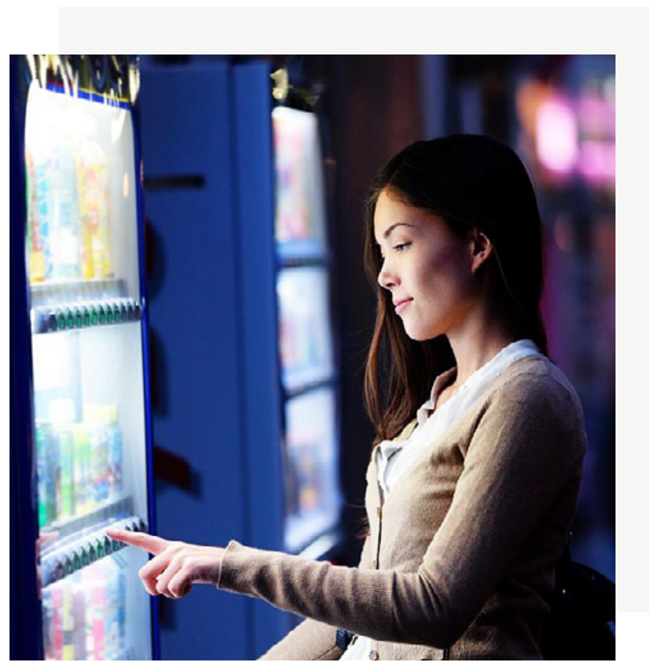


Figure 9 - Things will be able to say more about themselves with Bluetooth 5 advertising extensions

Larger Packets and Advertising Channel Offload

Bluetooth 5 allows packets to be up to 255 octets long. This is accomplished, in part, through offloading the payload to one of the other channels in the 0-36 channel number range, previously only used for connection events (a connection event is a time slot during which data may be transmitted over a connection). In addition to allowing larger packets in connectionless scenarios, this has other benefits which we'll come to.

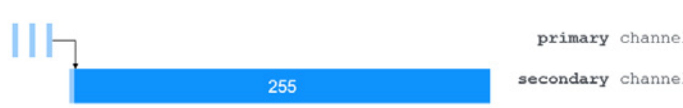


Figure 10 - Bluetooth 5 larger advertising packets and channel offload

6.0 Advertising Extensions

Only header data, including a new field called AuxPtr, is transmitted on channels 37, 38, and 39, which are now known as the Primary Channels in the context of Bluetooth 5 advertising. The AuxPtr field references the packet containing the advertising payload, which is transmitted on a secondary channel. It includes the channel number that the payload will be transmitted on so that receivers know where to find it.

Advertising Packet Chaining

For those use cases requiring even larger amounts of data to be broadcast, it's possible to chain packets together and for each packet to contain a different subset of the whole data set.

Each chained packet can be transmitted on a different channel, with the AuxPtr header field referencing the next in the chain.

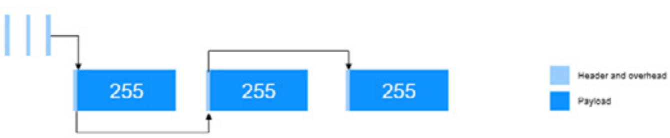


Figure 11 - Advertising packet chaining

Advertising Sets

Bluetooth 4 did not make provision for the advertising payload to vary. Proprietary extensions have emerged in the market to make this possible from some modules. Bluetooth 5 introduces a standard mechanism for having multiple, distinct sets of advertising data.

Advertising sets have an ID which is used to indicate which set a given packet belongs to and each set has its own advertising parameters, such as its advertising interval and the PDU type to be used. Advertising sets may use either the primary channels or the secondary channels. Critically, the task of scheduling and transmitting the different sets falls to the Link Layer in the Controller rather than it having to be driven by the Host, which would be far less power efficient. The Host needs only to inform the Controller of the advertising sets and their respective parameters initially, after which the Link Layer takes over.

Periodic Advertising

Advertising usually includes a degree of randomness inserted in the advertising event scheduling process. Random delays are deliberately inserted to help avoid persistent packet collisions. With Bluetooth version 4, this was the only way in which advertising could work. Bluetooth 5 introduces the ability to perform periodic and deterministic advertising, which allows scanners to synchronise their scanning for packets with the schedule of the advertising device. This can be a more power-efficient way to perform scanning and is also likely to pave the way for new uses of Bluetooth LE in connectionless scenarios, such as audio applications.

The Generic Access profile now defines a *synchronizable mode and a non-synchronizable mode*. When operating in synchronizable mode, a Periodic Advertising Synchronization Establishment procedure is defined.

Periodic advertising, performed in synchronizable mode, leverages a new header field called SyncInfo, which contains timing and timing offset information. Periodic advertisements use a new GAP PDU called AUX_SYNC_IND.

Reduced Contention and Duty Cycle

One of the many interesting things about the changes to advertising in Bluetooth 5 is the way in which radio channels are now used, with primary advertising channels 37, 38, and 39 carrying less data and secondary channels 0-36 doing most of the heavy lifting. With advertising data using all available channels, and only small headers using the primary channels, there will be less contention on those channels.
Furthermore, Bluetooth 4 transmits the same payload up

6.0 Advertising Extensions

to three times on three different channels. Bluetooth 5 now transmits such data once only, with small headers referencing it from the primary channels. The total amount of data transmitted is thus less and so duty cycle has been reduced

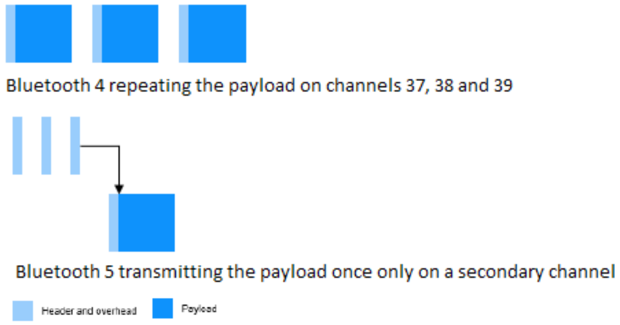


Figure 12 - Reduced contention and duty cycle

High Duty Cycle Non-Connectable Advertising

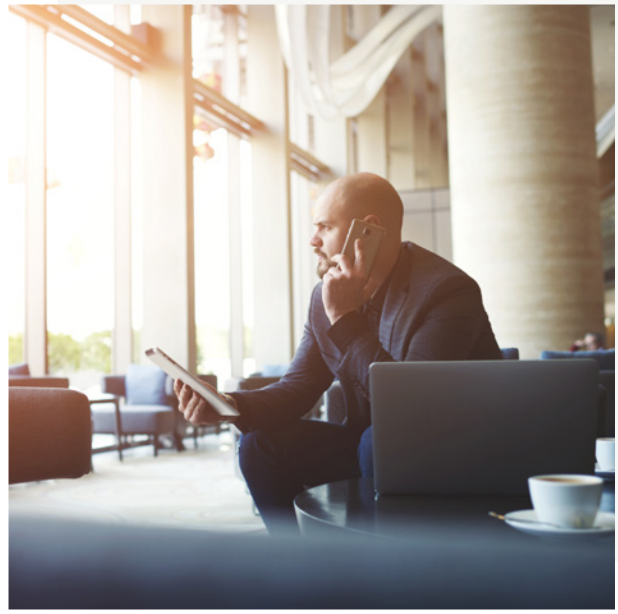
The minimum Advertising Interval has been reduced from 100ms to 20ms for non-connectable advertising. This will be of benefit in allowing a rapid recognition of and response to advertising packets from devices like beacons.

7.0 slot availability masks

7.0 Slot Availability Masks

Bluetooth 5 made some changes to help improve coexistence with other radio technologies on devices such as smartphones.

Bluetooth uses the 2.4GHz ISM band and this is immediately adjacent to the Mobile Wireless Standard (MWS) bands, such as are used for LTE. There's potential for interference between the two systems, with transmissions from one desensitizing the receiver on the other. Bluetooth 5 introduces a system called Slot Availability Masks, which allows Bluetooth to indicate the availability of its time slots and to synchronize in an optimal manner with the use of the adjacent MWS bands.



8.0 improved frequency hopping

8.0 Improved Frequency Hopping

Bluetooth uses Adaptive Frequency Hopping when in a connection. This is an algorithm which determines the radio channel to transmit and receive on and involves the selected channel changing frequently such that data is transmitted over a wide selection of channels. This helps make Bluetooth perform well in busy radio environments.

The Bluetooth 4 channel selection algorithm used in frequency hopping produced only 12 distinct sequences of channels and all packets in a given connection event would use the same channel, which is not optimal for some applications, such as audio.

Bluetooth 5 introduced a new channel selection algorithm called *channel selection algorithm #2*. Hopping sequences are now pseudo random and the distinct sequences which are possible are very large. Devices can indicate in connection parameters whether they support the new channel selection algorithm. Channel selection algorithm #2 makes use of a shared event counter, which ensures that each peer in the connection selects the same channel from the next available channel in a pseudo-random sequence.

9.0 the significance of Bluetooth 5

9.0 The Significance of Bluetooth 5

Bluetooth 5 represents another step change in Bluetooth technology.

Whole-home and building coverage is provided for with the new, long-range LE Coded PHY. The higher symbol rate of LE 2M improves spectral efficiency and supports emerging use cases in, for example, sports and fitness and medical equipment. Bluetooth's advertising extensions feature will pave the way for next-generation beacons, advanced audio applications and more. New industrial applications will become possible and some smart city applications too.

Bluetooth 5 will have a substantial impact in many sectors and further position it as the low power wireless technology of choice for the Internet of Things. ■

References

[1] Bluetooth SIG, Bluetooth 5 Core Specification
See https://www.bluetooth.com/specifications/bluetooth-core-specification